Picosecond, kW thin disc laser technology for LPP and FEL EUV sources

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Outline

- Picosecond solid state laser for LPP and FEL
- 100-kHz, ps beamline in HiLase Program
  - Compact 100-W, regenerative amplifier
  - 0.5-kW second-stage ring regenerative amplifier
- Summary

LPP EUV source and Hollow Shell formation by picosecond prepulse

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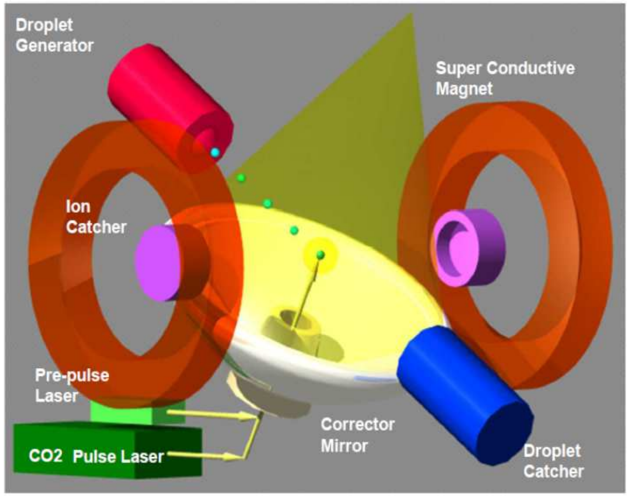
Power of light



Time history of Sn nanocluster Hollow Shell formation

Configuration of LPP EUV source with picosecond prepulse

Experimental and theoretical studies of tin droplets shaping by picosecond laser pre-pulses (S24) (Invited)
Slava Medvedev et al, EUV Labs, Russia

Metal photocathode for long lifetime and stability

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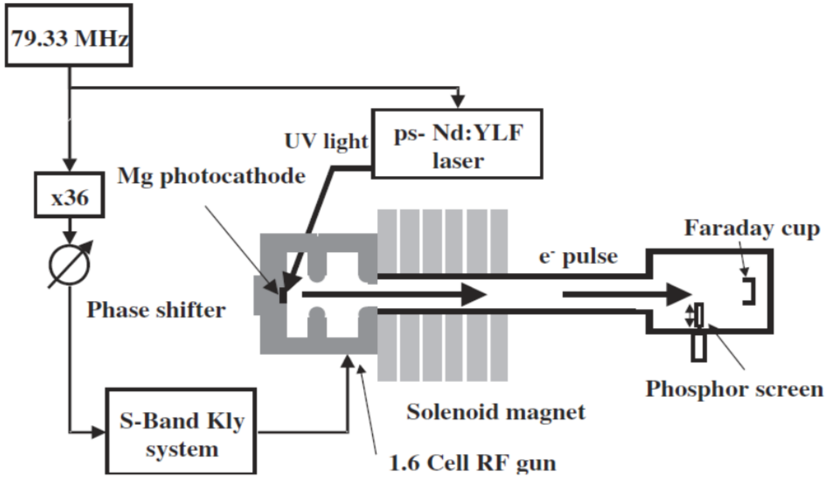


Fig. 3. Schematic diagram of the Mg cathode performance test system.

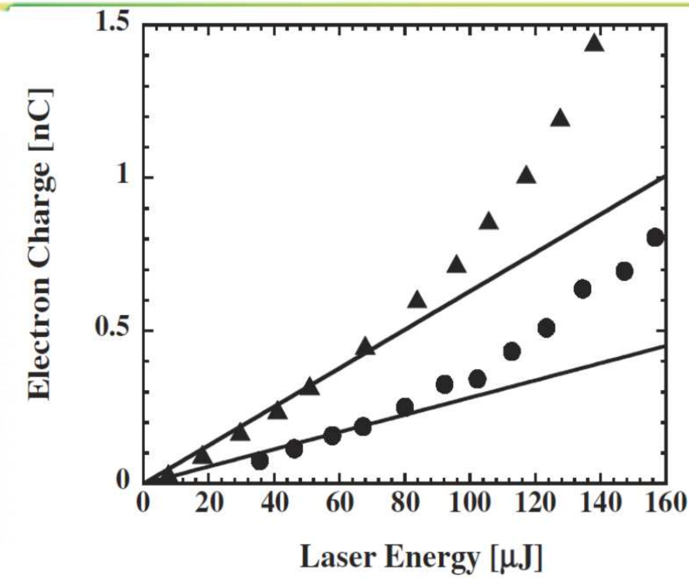


Fig. 5. Emitted electron charge from the Mg cathode as a function of the laser (349 nm) energy before (●) and after (▲) laser cleaning. The lines represent the best fit of the data at the laser energy <80 µJ.

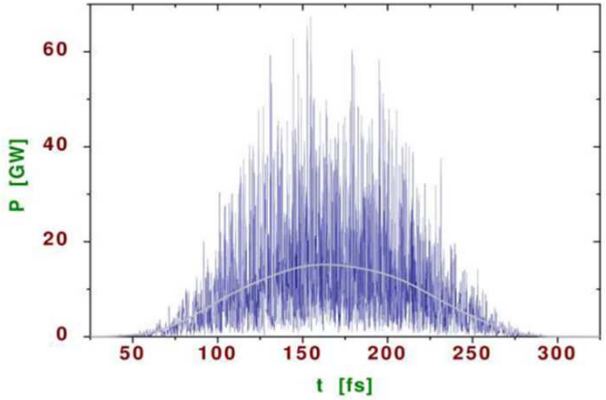
100µJ x 10MHz = 1kW, several ps at 3HG

Jpn. J. Appl. Phys. Vol. 42 (2003) pp. 1470–1474
Part 1, No. 3, March 2003

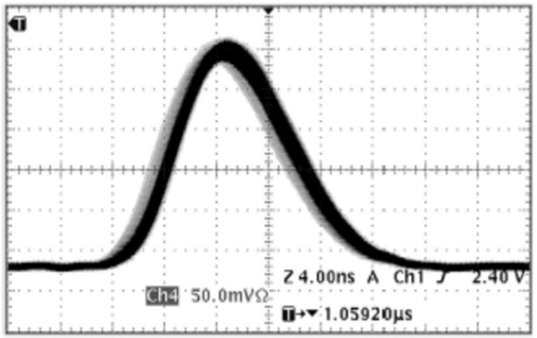
Quantum Efficiencies of Mg Photocathode under Illumination with 3rd and 4th Harmonics Nd: $LiYF_4$ Laser Light in RF Gun

Terunobu NAKAJYO, Jinfeng YANG, Fumio SAKAI and Yasushi AOKI

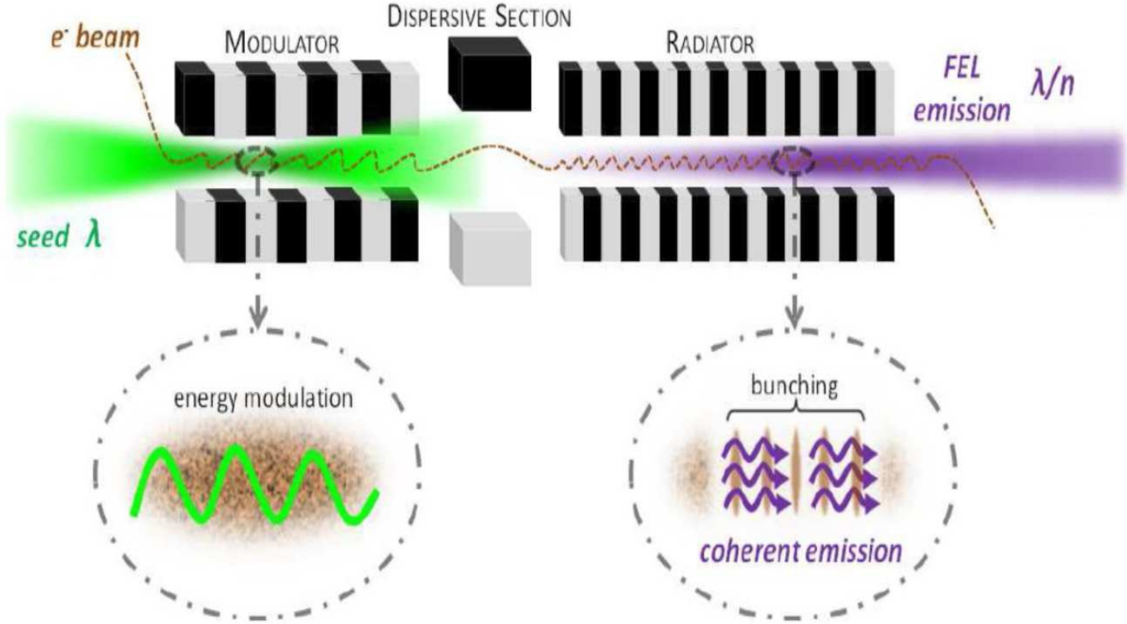
Temporal smoothing of FEL pulses by UV picosecond laser seeded HGHG



SASE FEL pulse shape



100µJ x 10MHz = kW, 1ps, 4HG



Schematic of the working principle of a HGHG free-electron laser.

Chirped pulde a,plification in X-ray free electron lasers
Hugo Ducasa et.al. SPIE 9585-15, San Diego 2015

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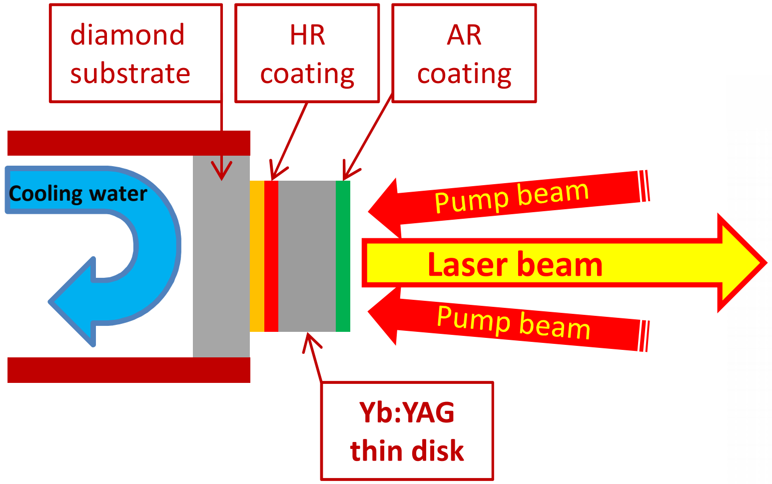
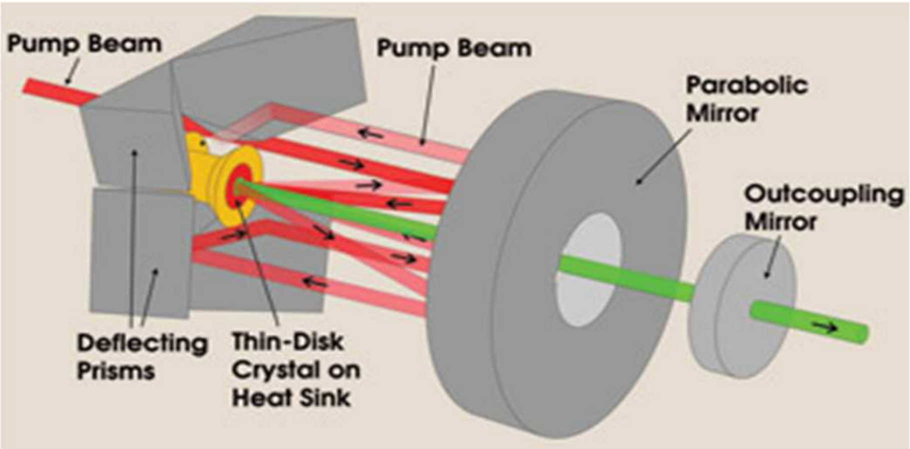
Yb:YAG thin-disks for the regenerative amplifiers





Thin disk parameters:

- 220 μm thickness
- 10 mm diameter
- 7.2 at.% Yb^{3+} doping
- water-cooled
- radius of curvature 3.9 m, increases under intense pumping - careful cavity design
- low gain → regenerative amplifier

100-W high-repetition-rate regenerative amplifier

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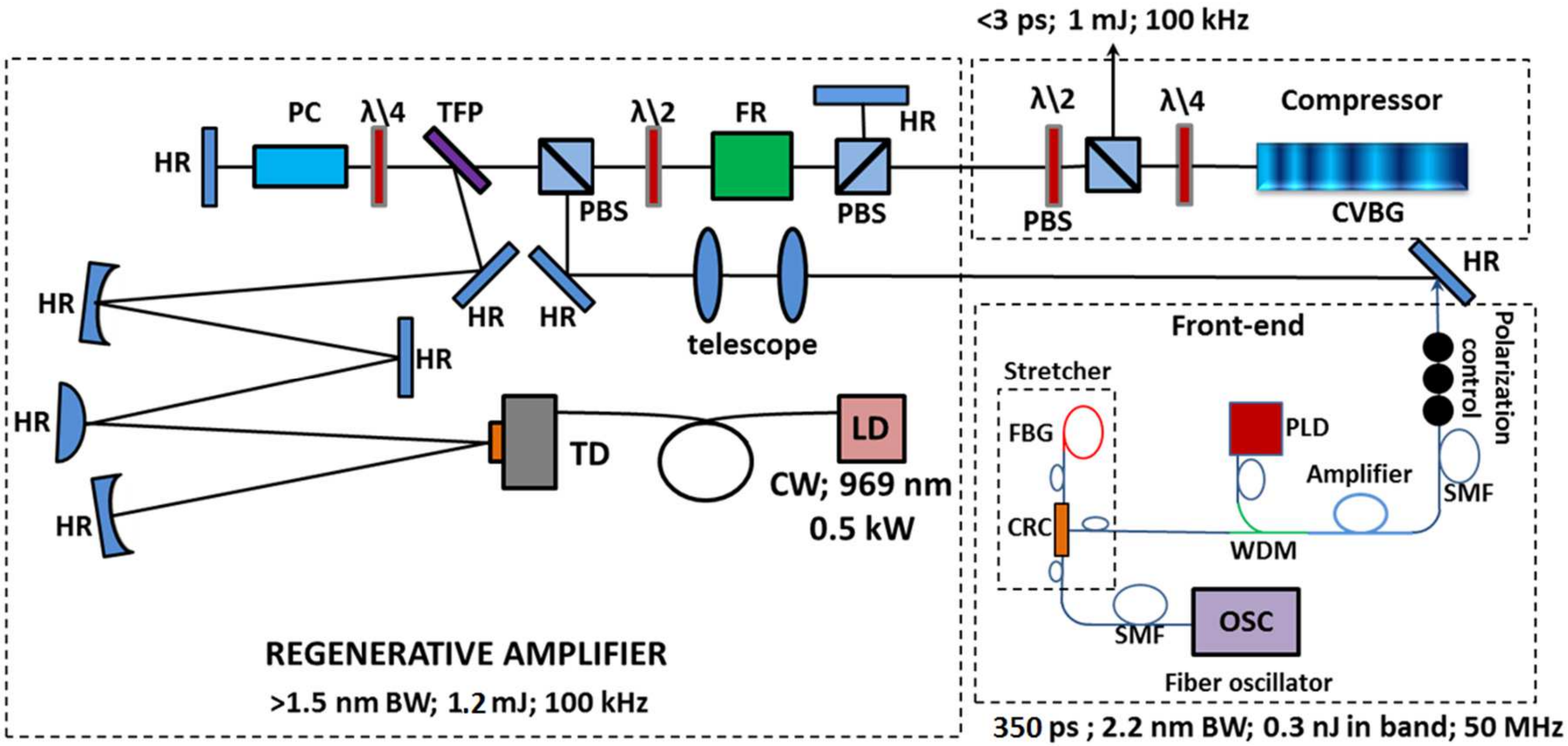
Power of light



- Small-scale (0.9 x 1.2 m^2) thin-disk Yb:YAG regen
- Zero-phonon-line pumping (969 nm)
- Up to 35% optical-optical eficiency
- Fundamental spatial mode ($M^2 \approx 1.4$)
- Pulse compression below 2 ps, BW 0.8 nm
- 8x8x25mm BBO home-made Pockels cell
- CVBG compressor (up to 85% efficiency)

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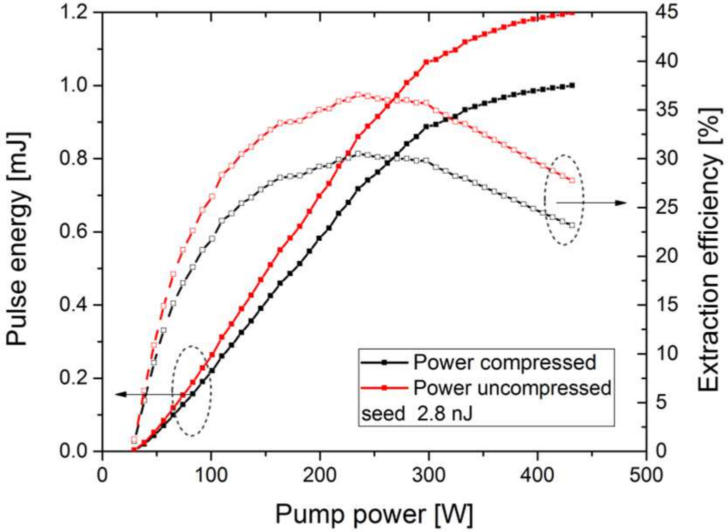
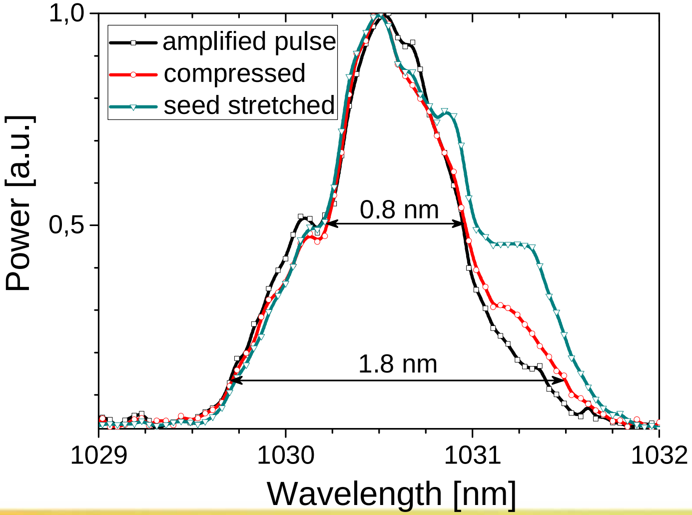
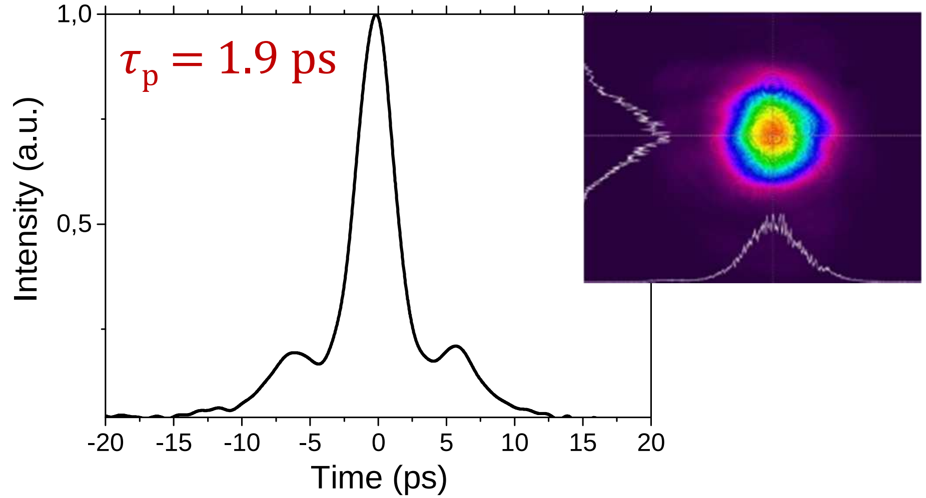
100-W regen: Output parameters



- Maximum uncompressed pulse energy 1.2 mJ
- Bandwidth after compression 0.8 nm (FWHM
- Intensity autocorrelation sech^2 fit 1.9 ps, pulse bandwidth limit 1.4 ps (sech^2)
- AC wings – third-order dispersion has to be compensated
- Output used for generation of 2nd and 4th harmonics
  - 6 W at 257.5 nm from 60 W at 1030 nm





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Fourth harmonic

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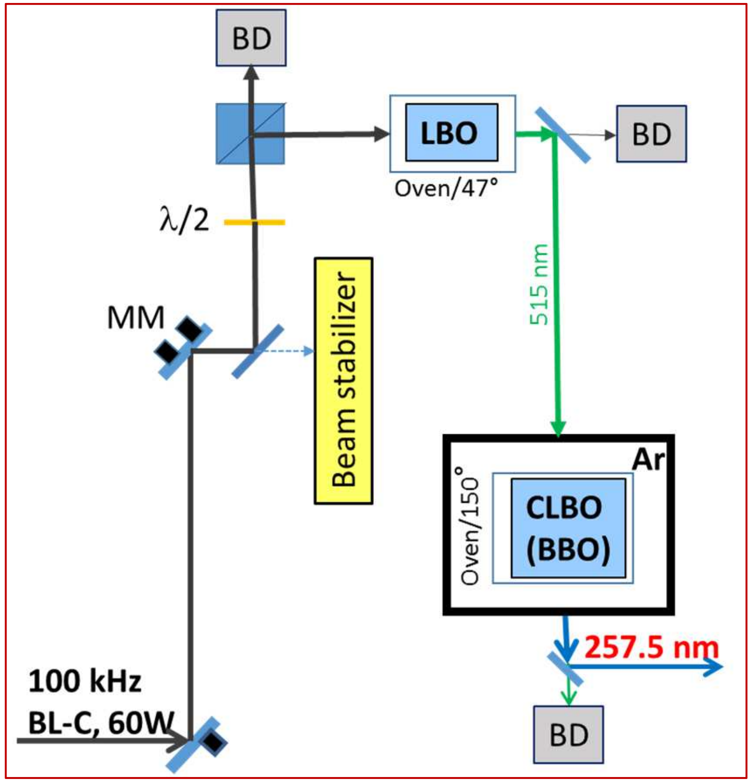
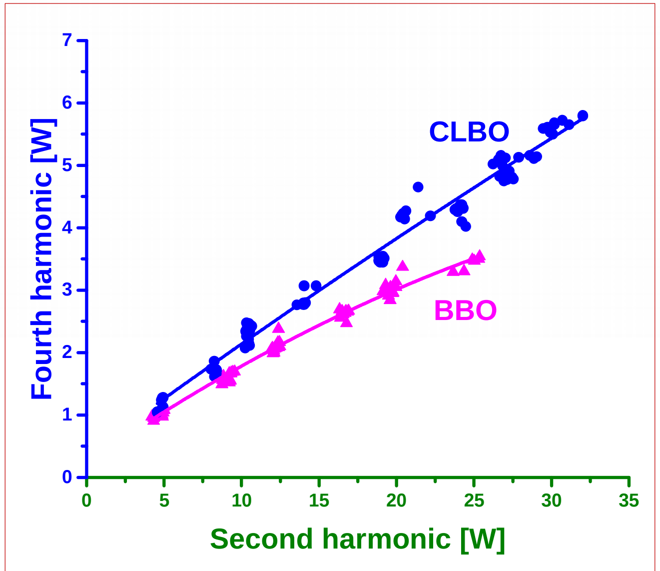
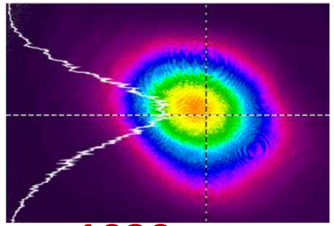




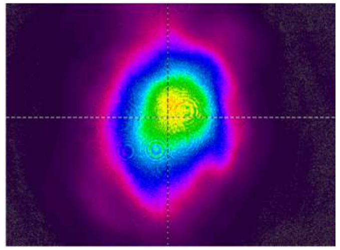
4H/2H conversion:

CLBO 18%

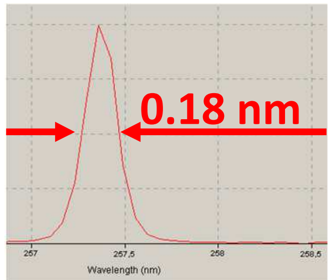
BBO 14%



1030 nm

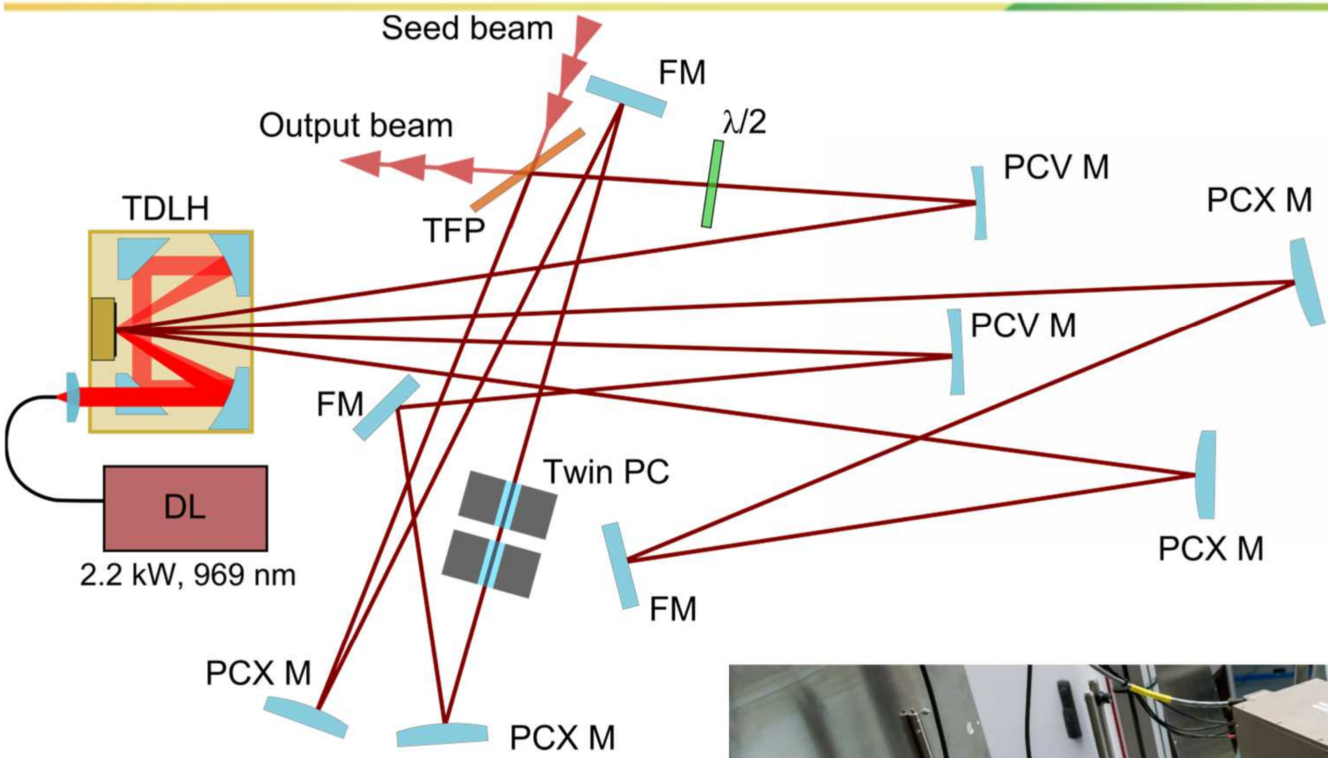


515 nm



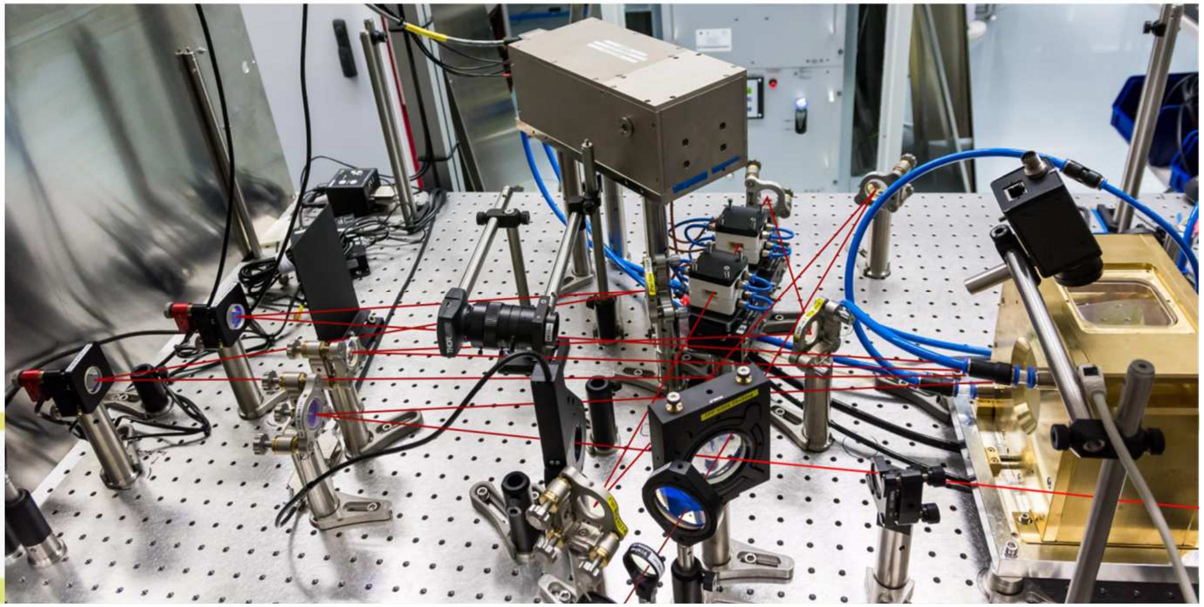
257.5 nm

Ring cavity for 500-W regen



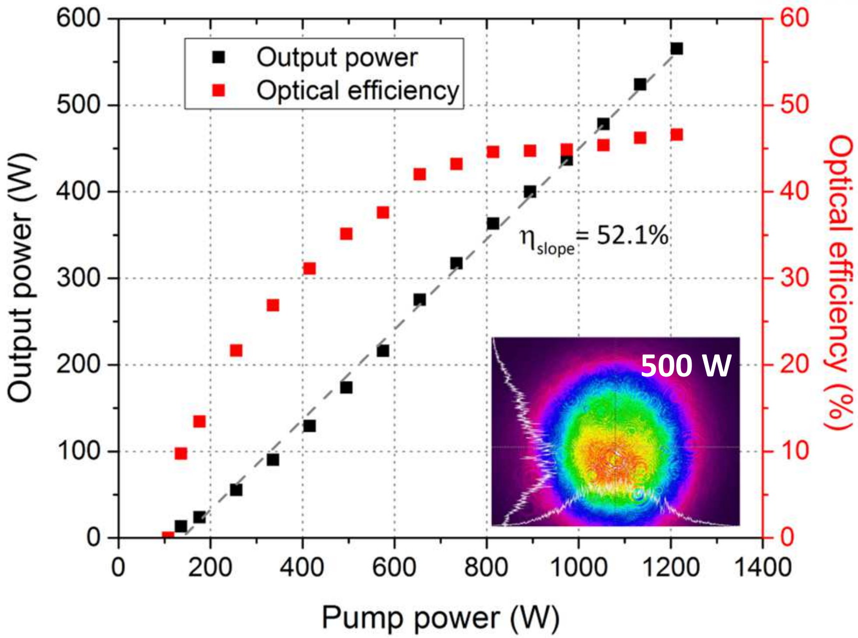
- Why ring cavity?
  - shorter cavity with given mode sizes
  - better pulse-to-background contrast
  - isolation from the seeding laser
  - lower gain per roundtrip

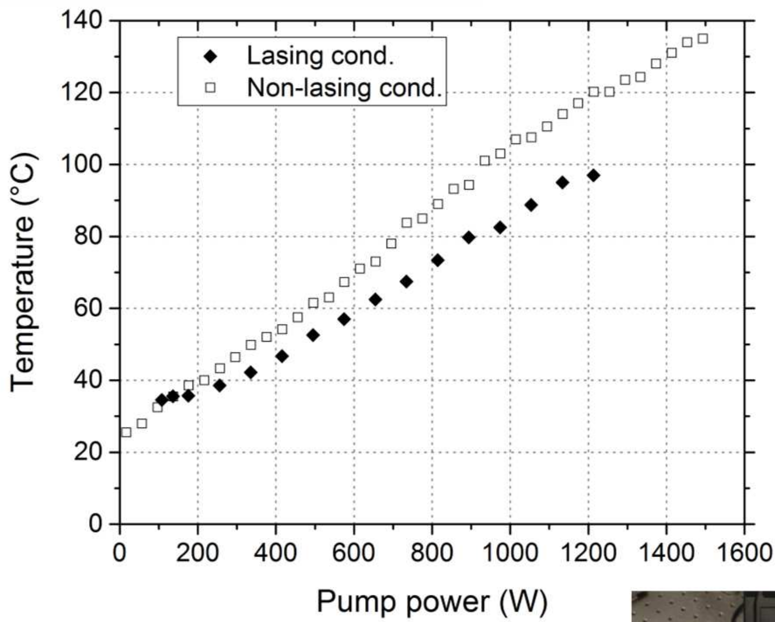
- Compact layout: 6.5-m long cavity with $1 \times 0.6\ m^2$ footprint
- 5.2-mm pump spot



500-W regen: Test in CW operation

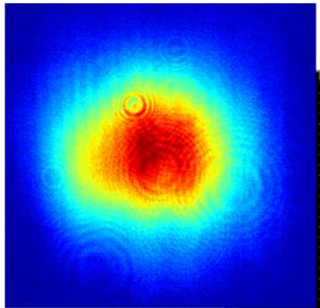
- Cavity first tested in CW without the Pockels cells
- Fundamental spatial mode
- Maximum power 565 W at 1.21 kW pumping (opt. efficiency 47%)
- Disk temperature well below its operational limit

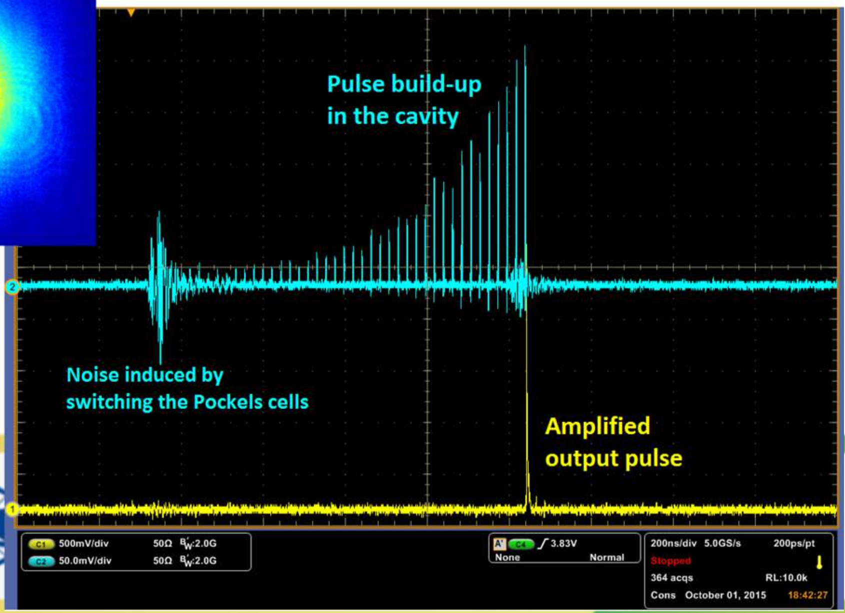


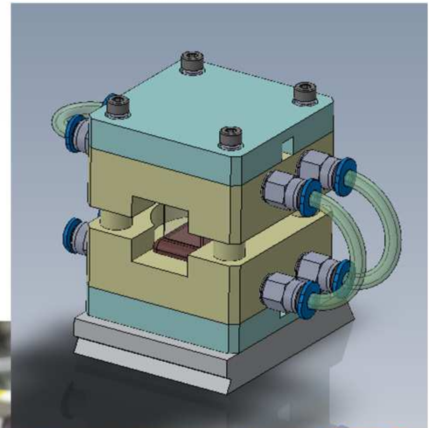


500-W regen: Seeded operation

- Half-wave voltage 7.1 kV – home-made Pockels cells
- Due to several technical problems, we started with pulse amplification very recently
- Cavity alignment is still being optimized
  - currently with ≈ 2 W seed and moderate pump power, - 130-W output power obtained
- Good contrast of the output pulse







Intermediate Summary

- Compact 1-mJ/100-kHz regenerative amplifier operational
  - fundamental spatial mode operation
  - pulse compression below 2 ps
  - 4HG by 10% efficiency
- 5-mJ/100-kHz second-stage regen under development
  - over 500 W output demonstrated in CW operation pulse amplification achieved

Future Perspective

- Picosecond mJ, 100kHz (100W) laser available for LPP
- >10kW EUV FEL needs advanced picosecond laser technology

  10kW, >10MHz, picosecond laser for kW THG, FHG